

STEADY STATE THERMAL ANALYSIS OF STEPPER MOTOR, USED IN AUTOMOBILE HVAC BLEND DOOR ACTUATOR

ADHIRATH MANDAL¹ & HAENGMUK CHO^{2*}

¹Research Scholar, Department of Mechanical Engineering, Kongju National University, Republic of Korea

²Professor, Department of Mechanical Engineering, Kongju National University, Republic of Korea

ABSTRACT

Heating ventilation and air conditioning system have gained a lot of popularity for passenger comfort in vehicles. Till now the mixing of the hot air and cold air was achieved by movement of the blend door with the help of a lever. Achieving the optimum temperature inside the cabin required movement of the blend door continuously. HVAC system helped in achieving the optimum temperature with the help of a blend door actuator. The blend door actuator continuously adjusts the amount of hot and cold air mixture, for passenger comfort. For the blend door actuator till now DC motor were being used, which used to consume more current. A feedback system was also necessary for the dc motor. But with the use of a stepper motor in the blend door actuator, many advantages could be attained. The feedback system was not required by a stepper motor and was more accurate than dc motor. The main advantage of the stepper motor was it utilized less current. As stepper motor was being proposed to be used in the blend door actuator, it was important to analyse the heat generated in the stepper motor. This paper focuses on the heat generated by the coil of the stepper motor and how the heat flows from the coil to the stator through the bobbin under natural convection condition was analysed. The model was analysed under steady state thermal condition.

KEYWORDS: Stepper Motor, Steady State Thermal, Blend Door Actuator, Hvac & Natural Convection

Received: Jun 25, 2019; **Accepted:** Jul 15, 2019; **Published:** Sep 24, 2019; **Paper Id.:** IJMPERDOCT201979

1. INTRODUCTION

Human comfort or thermal comfort of the human is a condition in which the body and mind feel in a state of comfort. The condition state is different for every human being. A human can work efficiently if the environment temperature is satisfactory. To make the environmental condition comfortable for human beings, an eating system and air conditioning system are used. The air conditioning system works with the help of a cooling refrigerant and the heating system works with the help of heating element. These days the heating ventilation and air conditioning system are gaining popularity. Heating ventilation and air conditioning (HVAC) system help in providing a comfortable climate to the persons residing in the building. With the advancement of technology and rising importance being given to thermal comfort in the automobile sector, HVAC system is becoming popular in the automobile.

Before the use of HVAC system, the air-conditioning and heating system were used to control the cabin temperature. When cold air is required, the air from outside is passed through the condenser. To cool the condenser, refrigerant is used. The refrigerant is first compressed and then passed through the condenser. The refrigerant cools the condenser. The air from the outside passes through the condenser and releases the heat to the condenser and the cold air passes into the vehicle cabin.

In the case of hot air requirement, the air passes first through the condenser and then through the heating core. During hot air the refrigerant does not pass through the condenser. The heating core is heated with the help of hot radiator fluid. The engine heat is absorbed by the radiator fluid and then the heating core is heated by the hot radiator fluid. The air passing through the heating core which gets warm and then in turn make the cabin warm. This type of system could only cool the cabin or make the cabin warm. To achieve a comfortable temperature the air has to be mixed. The mixing of the air is controlled by the blend door. The blend door is controlled by the HVAC system. The blend door is moved with the help of an actuator. The actuator controlling the blend door is generally known as blend door actuator.

An Actuator is a device or operational element that associates the electronic system to the nontechnical process. It is mainly used for the control of energy actuators, volume & mass. Output is mainly energy and power, mechanical work is the general output. To control the actuator low electrical power is used. Actuators are mainly of six different types:

- Electro Hydraulic Actuator
- Piston Actuator
- Electro Mechanical Actuator
- Diaphragm Actuator
- Vane Actuator
- Electro Pneumatic Actuator

Generally, in an HVAC door blend actuator, electromechanical actuator is used. Electromechanical actuator is very versatile and are mainly required by different valve actuation. Different could be produced by the actuator. The motion could vary from 360° rotations to multiple revolution and partial turns ranging from 45°, 30°, 180°, 270°, 90°[1].

For the movement of the blend door, an electric motor is being used in the actuator. For the movement of the blend door, the stepper motor can also be used. Stepper motor is also known as a Brushless synchronous electric motor. The output of a stepper motor is the mechanical rotation whereas the input signal is the electrical pulse. The steps in a stepper motor are generally 200 steps. It moves one step in one electrical signal. No feedback system is required for the stepper motor as the motor only rotates one step in one electrical pulse, therefore it can be used in open loop system and no feedback system is required. There are two types of stepper motor, permanent magnet and variable reluctance stepper motor. Permanent magnet stepper motor has a permanent magnet rotor and a soft iron stator. A variable stepper motor has a soft iron rotor and stator [2]. The Stepper motor has a lot of advantages.

- Rotation is fixed, and depends on the electric pulse
- Does not require feedback system
- Full torque is achieved, at energized winding
- Input pulse can modulate wide speed range

Therefore, using stepper motor in the blend door actuator would help in increasing the life and durability. It is important to conduct the thermal analysis of the stepper motor. As the actuator is in a closed box it is important to see the heat affected are by the hot coil, and how it would affect the stator and how much heat would be transferred from the coil to the stator. This paper is focused on the thermal analysis of the stepper motor.

2. LITERATURE REVIEW

Tomoaki Yano et al., researched the spherical stepper motor and its basic characteristics. The author experimented with a small stepping motor which was developed and had two degrees of freedom. Two sub stepping motor was compiled in the motor. Each of the sub motor are semi-circle in shape and was bipolar linear stepping type. Rotational axis crossed the same point, of the two sub motors. This helped the motor to move in any direction. In the experimental study it was concluded that the output shaft could be held in any direction by the motor. The resolution of the inner sub motor was 0.01° whereas for the outer sub motor had a resolution of 0.03° . holding torque was also calculated and was found that the inner sub motor had 0.2 Nm and that of the outer sub motor was 0.03Nm. I was observed that as the torque was not enough, the motor could not be used at the base joint of the manipulator but because of the high resolution, the motor could be applied to the wrist joints. This small torque and high resolution could also be used to apply the motor in the robotic eyes which use charge-coupled device camera. The author also compared the spherical motor that were produced earlier, and found that the new motors resolution was not bad compared to old and the torque was not very good. Because of these characteristics the motor could be used as eyes in the robot and the wrist joints

[3]. Brian Lawrence Boland et al., explored the effect of a pneumatic motor (plastic four-cylinder piston). which was used in the magnetic resonance imaging system instrument. MRI is used in many diagnostic purposes and to acquire the real-time benefit need for MRI compliant to a surgical device is needed. To drive an MRI instrument an actuation mechanism is required. Stepwise motion was controlled in the motor by the help of using a pneumatic valve. Use of a pneumatic control made the motor free from metal and for the operation of the motor does not require electricity for operation. For the controlled and accurate movement, required in the MRI guided inventions, stepping nature of the stepper motor was best. To increase the torque of the motor gear arrangements were incorporated in the motor. The output torque and the rotational speed depends on the load condition and the air pressure. 19N mm of torque was achieved by the stepper motor and a speed of 2000rpm. The paper concluded the design of a pneumatic stepper motor of high speed, which could be used in a magnetic resonance imaging system instrument, without affecting the quality of the image [4].

Christoph Gradl et al., presented a stepper motor (linear hydraulic stepper motor) which could be used in positioning tasks without sensors in hydraulics. Precise motion steps are generated by the pulses which are transferred to the switching valves. The stepper motor drive is completed by the use of a hydraulic cylinder piston. This cylinder piston moves a discreet amount of fluid by a limited forward stroke. Arrangements for the test were made to check the results of the hydraulic stepper motor with a hydraulic cylinder.

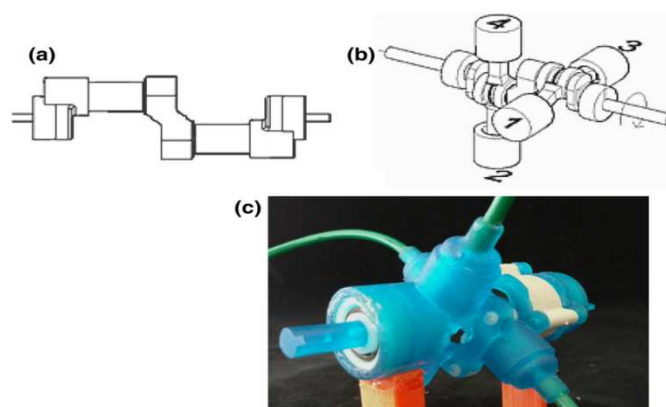


Figure 1: Assembled Motor CAD and Actual Image [4].

The test was conducted to ascertain the performance of linearity, positioning accuracy, scattering range and repeatability of the drive. For the testing and investigation two different step sizes were used i.e 5 μm and 15 μm . For estimating the sensorless position estimation, a computation model was developed. The test results showed that the accuracy at all test condition of the model was good. There was fleeting valve leakage which was because of pressure peak phenomena, because of this the accuracy degenerated. The Deflection of elastic beam was controlled by the sensor less control, example was studied. With the use of the loop simulation, testing of the hardware was carried out. In the experimental testing the beam force was exerted on the stepper motor by the help of a controlled hydraulic force [5]. Kiran R. Kambly et al. studied the Heating ventilation and air conditioning systems energy consumption in plug-in electric vehicle. The plug-in electric vehicle stores energy from the electric grid and uses this energy for powering the vehicle and operating its accessories. As electric vehicle use stored energy, usage of HVAC system in an electric vehicle would use energy from the stored energy. This would reduce the distance range of the electric vehicle. The cabin condition depends on the primary drivers, factors like local ambient temperature, local humidity, thermal soak, local solar radiation and length of the trip. The paper concentrated on the use of HVAC system in the electric vehicle and measure the vehicle performance which would include the range and energy consumption. The author considered charging behaviour, local weather, driving behavior, solar loads, and regional passenger fleet population for energy consumption by the HVAC system. HVAC system would reduce the distance range of the electric vehicle. It was also emphasised that, if the efficiency of the HVAC system is improved, this would improve the efficiency of the electric vehicle [6]. B. Melka et al. experimented on a permanent magnet brushless DC motor to validate the flow and thermal processes. Heat transfer and air flow of the permanent magnet brushless DC motor was modelled for inside and outside the case. The heat transfer was coupled with the heat source and the heat conduction from the heat generation parts like bearings, windings and magnets, forced convection and natural convection, radiation phenomena in the external and internal air region was examined. The motor model contained PCB (printed circuit board), magnet circuit, rotor, neodymium magnets, windings, plastic cover and air between the parts. Velocity and temperature fields were the parameters on which the developed model was validated. For measuring the temperature on the motor housing, seven temperature anemometers were used at 4 levels. 25 thermocouples and laser doppler anemometer were used inside and outside the motor. Numerical and experimental trials were conducted at 3 rotational speeds and 4 loading conditions on the motor. 9°K temperature error was observed at the internal points and 2°K was observed at the external point. Prediction of the velocity field was close in terms of the two components ie. Vertical and horizontal in the housing wall. The temperature on the winding was recorded to be 78°C [7].

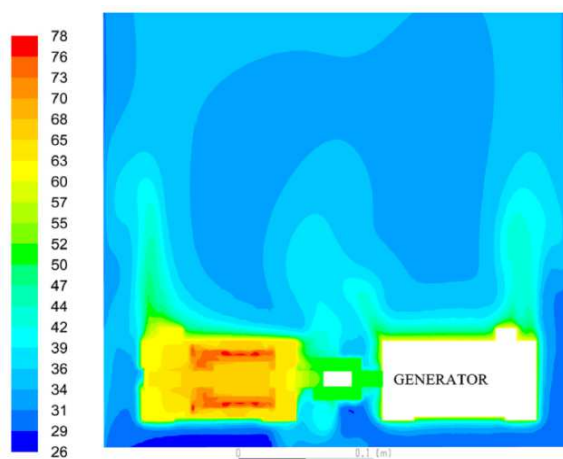


Figure 2: Heat Generation in a Motor[7].

3. BLEND DOOR ACTUATOR

Blend door actuator is used for the movement of the blend door. The blend door helps in the mixing of the hot air and cold air. Figure 3 shows an actuator made for use in HVAC system. Figure 4 shows a block diagram where the actuator is placed and the connection with the blend door.

The internal components of the actuator are shown in figure 5. The main components are the front cover, Back cover, Core, coil, bobbin, magnet, gears for better torque and the printed circuit board for the control of the stepper motor.

Working of Actuator

The actuator has a motor. In our model, the motor is a stepper motor. Stepper motor is an electromechanical device that helps in the conversion of the electric power to mechanical movement (rotational movement). The theory of operation of magnets are used in the stepper motor for operation. A stepper motor can divide a full rotation in to a number of steps (specific angle). When voltage is applied to the terminals of the motor it rotates. There are multiple tooth electromagnets and they are arranged around a central gear-shaped of iron. The electromagnet is excited by a control circuit (microcontroller). When the shaft has to be turned , one of the electromagnets is excited, which creates a magnetic force ad attracts the gear magnetically. To rotate the shaft more the next electromagnet is excited and then the next electromagnet. The small rotation taken by the shaft when electromagnet is supplied with energy is known as a step. The motor goes not rotate continuously; it rotates in steps.



Figure 3: Blend Door Actuator.

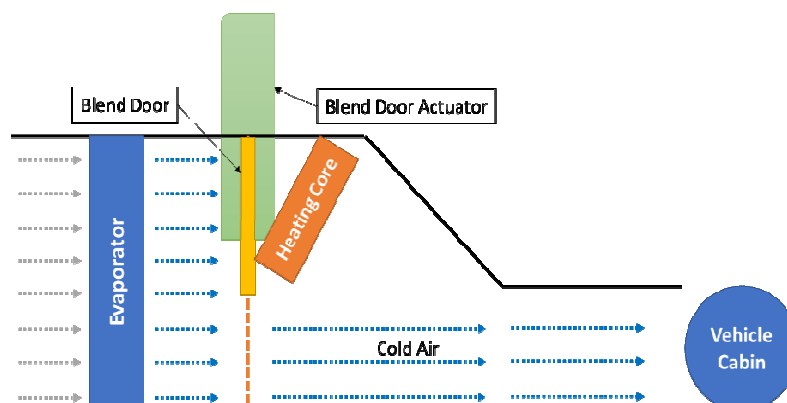


Figure 4: Block Diagram of Air Conditioning and Heating Setup[8].

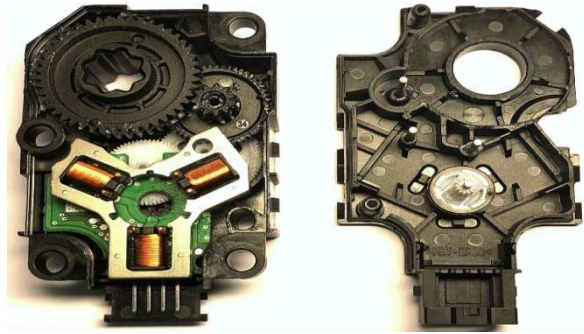


Figure 5: Actuator Components.

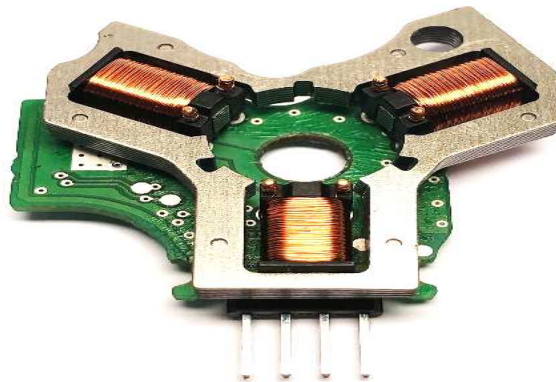


Figure 6: Coil and Stator of Stepper Motor.

The simulation was carried out on the coil, stator and the bobbin of the stepper motor. Figure 7 shows the 3D model of the stator, coil and bobbin.

Materials

To have proper results of heat transfer and the amount of heat generated in the part, materials play a very important role in the simulation. The materials chosen for the parts have been summarised in the table.

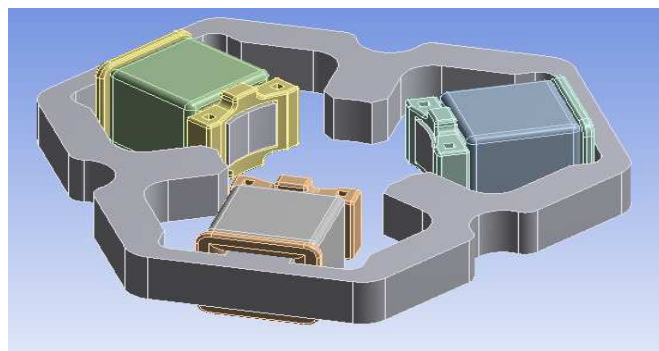


Figure 7: 3D Model of Stator, Coil and Bobbin.

Table 1: List of Materials for the Parts

Part Time	Material
COIL	Copper
BOBBIN	Polybutylene Terephthalate with 30% glass fibre
STATOR	Non oriented electrical steel

Steady-State Thermal Analysis of the 3D Model

Steady state thermal analysis is almost similar to the transient thermal analysis. The procedure is also similar. The main difference is that in transient state thermal analysis the load is a function of time. In this model the simulation is processed for 3600 seconds.

The whole model is modelled in Catia and then imported to ANSYS 16 workbench. From the literature review it was observed that the coil of the motor reached a temperature of 78°C [7]. All the three coil in the model were ramped to a temperature of 78°C. Meshing of the whole model was carried out. The element size was 0.50 mm and the minimum edge length of the mesh element is 0.000083 mm. Figure 8 shows the meshed model.

Convection Condition

Convection is applied to the model. Considering the convection at free air convection at the required temperature of 30°C. As the actuator will be in the car cabin there won't be any forced convection, therefore free convection has been considered. The heat transfer coefficient for convection, free air is between 5–25 (W/m². K). In this analysis the convection heat transfer coefficient value was 5.9 (W/m². K).

The thermal conductivity of the material was considered from different sources.

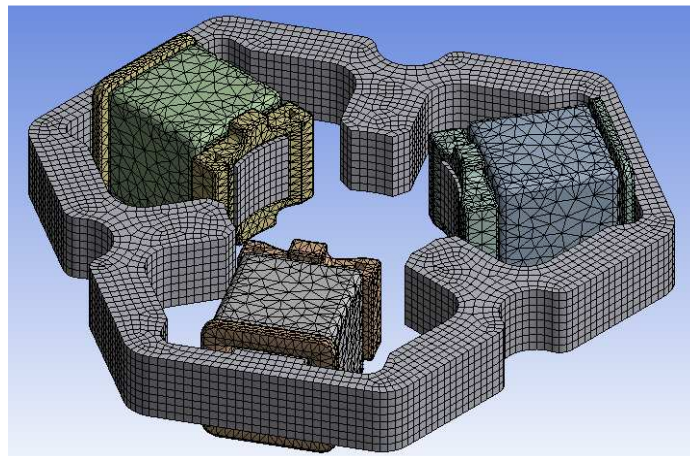


Figure 8: Meshed Model.

Table 2: Thermal Conductivity of Materials

Material	Thermal Conductivity (W/Mk)
COPPER	385[9][10]
POLYBUTYLENE TEREPHTHALATE WITH 30% GLASS FIBRE	0.24
NON-ORIENTED ELECTRICAL STEEL	50.2

4. RESULTS AND DISCUSSIONS

The results from the analysis showed that the coil and the bobbin had the maximum temperature of 78°C. but some elements of the bobbin had a lower temperature. The temperature was lower at the inner parts. The lowest temperature was around 57.2°C as shown in figure 9. where as in the case of the stator the maximum temperature was recorded at the junction of the stator and the bobbin. The maximum value of the temperature recorded at the junction was 72°C. The minimum temperature was 67.3°C.

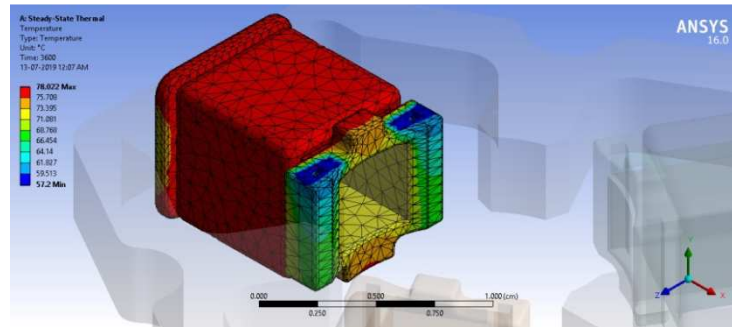


Figure 9: Temperature Distribution at the Coil and Bobbin.

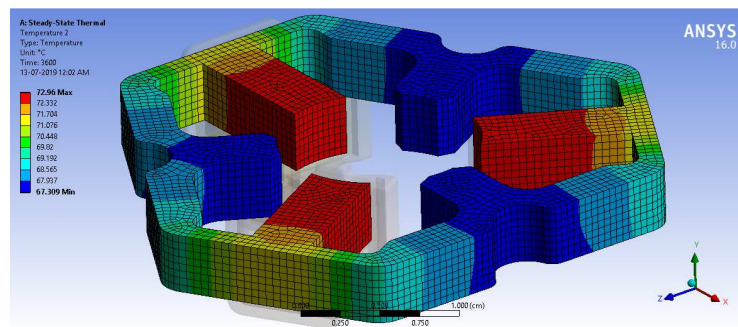


Figure 10: Temperature at the Stator.

Figure 11 shows the total temperature distribution at the three parts of the motor i.e the coil, bobbin and the stator. It is clearly visible that the main heat generated by the coil is transferred to the bobbin but because of its low thermal conductivity and natural convection the temperature is restricted to the bobbin. The maximum temperature is not transferred to the stator.

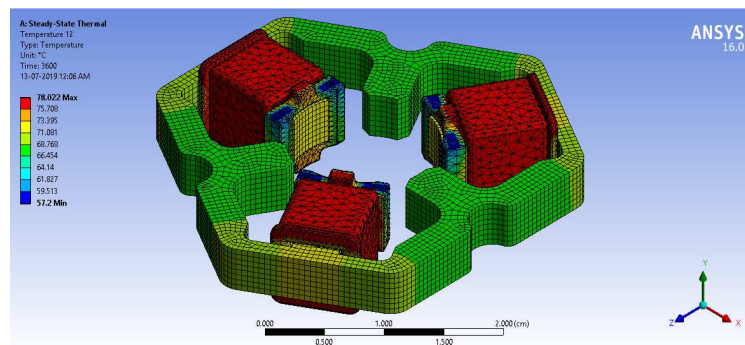


Figure 11

5. CONCLUSIONS

Heating ventilation and air conditioning have been popular because of the thermal comfort it offers to the inmates inside a building. With the rising use automobile in different climate conditions, the comfort of the passenger have acquired importance. For controlling the temperature of the cabin HVAC are important. The climate could only be controlled by the blend door, which is controlled by the blend door actuator. The use of step motor in the blend door actuator would utilize less energy and the movement of the blend door will be accurate as it does not rotate it moves in steps. As stepper motor is being used in the blend door actuator it was important to conduct the heat analysis of the motor to understand the maximum heat generated and the effect of the heat on the connected parts of the motor. From the simulation it was

observed that the maximum heat was generated at the coil and the bobbin which was connected to the coil. The maximum temperature value recorded was 78°C whereas the minimum temperature recorded was 57.2°C. This temperature was recorded in the condition of natural convection by air. Because the stepper motor is in a closed box the value of natural convection was valued at 5.9 W/m². K.

6. ACKNOWLEDGMENT

This work was supported by the Technological Innovation R&D Program (No: S2518003) funded by the Small and Medium Business Administration (SMBA, Korea).

REFERENCES

1. Brian Nesbitt. (2007). *Handbook of Valves and Actuators*. United Kingdom: Elsevier Ltd.
2. Muhammad H. Rashid. 2018. *Power Electronics Handbook, Fourth Edition*. United Kingdom: Elsevier Inc.
3. Tomoaki Yano, Takeo Suzuki. 2002. "Basic Characteristics of the Small Spherical Stepping Motor". *Proceedings of the IEEE*. 1980–1985
4. Bosco, S. J., Wolfgang, N., Bonaventure, D., & Tibi, B. (2015). *Disassemblability and Reassemblability Parameters Analysis: Automobile Maintenance Context Study*.
5. Brian Lawrence Boland, Sheng Xu, Bradford Wood, Zion Tsz Ho Tse. 2018. "High Speed Pneumatic Stepper Motor for MRI Applications". *Annals of Biomedical Engineering*. 47. 826–835.
6. Christoph Gradl, Andreas Plöckinger, Rudolf Scheidl. 2016. "Sensorless position control with a hydraulic stepper drive - Concept, compression modeling and experimental investigation" *Mechatronics*. 35. 91–101
7. Kiran R. Kambly, Thomas H. Bradley. 2014. "Estimating the HVAC energy consumption of plug-in electric vehicles" *Journal of Power Sources*. 259. 117–124
8. Sures, H. *Fortification and Culpability Analysis of Three Phase Induction Motor using Labview*.
9. B. Melka, J. Smolka, J. Hetmanczyk, Z. Bulinski, D. Makiela, A. Ryfa. 2018. "Experimentally validated numerical model of thermal and flow processes within the permanent magnet brushless direct current motor". *International Journal of Thermal Sciences*. 130. 406–415
10. Adhirath Mandal, Haengmuk Cho. 2019. "Stepper Motor Actuator ForHvac Blend Door – A Review". *International Journal of Mechanical and Production Engineering Research and Development (Ijimperd)*. Vol. 9, Issue 4. 333–346
11. Ravichandran, N. A Study on Inventory Management with Reference to Leading Automobile Industry. *International Journal of Management, Information Technology and Engineering*, 15.
12. Nick Simpson, Rafal Wrobel, Phil H. Mellor. 2013. "Estimation of Equivalent Thermal Parameters of Impregnated Electrical Windings" *Ieee Transactions on Industry Applications*. 49. 2505–2515
13. L. Siesing, A. Reinap, M. Andersson. 2014. "Thermal properties on high fill factor electrical windings: Infiltrated vs non infiltrated". *International Conference on Electrical Machines*
14. Kayode, G. M., Borode, M., & Adedokun, M. O. *Community Driven Development Project: A Study on The Impact of Motorized Borehole Water Project in Irasa, Ado-Ekiti, Nigeria*.
15. Cengel, Y. A. (2002). *Heat Transfer: A Practical Approach*. 2nd Edition, New York: McGraw-Hill.

AUTHORS PROFILE



Adhirath Mandal: He has completed his bachelors in Mechanical & Automation Engineering from Guru Gobind Singh Indraprastha University, Delhi, India. After his graduation he has worked in an water RO company for 1 year. He completed his M.Tech (masters) in production engineering from Delhi Technological University, Delhi, India. He has worked as Assistant Professor in engineering colleges in Delhi NCR. He has teaching experience of 3.5 year. He is pursuing his doctoral degree from Kongju National University, Cheonan, Korea in mechanical engineering. His area of interest is Biodiesel and electric vehicles. He has published papers in national and international journals. The papers are indexed in Scopus.



Professor HaengMuk Cho (corresponding Author): He is a renowned professor in South Korea. He is working as professor at Kongju National University in S.Korea. He did Post Doctorate Fellowship from Department of Automotive Engineering of Lough brough University in UK and North Texas University in USA. He earned his PhD from Hanyang University, South Korea in 1997 and completed his M.D. in Environment Engineering from Yonsei University in S Korea. He is working on national and international projects in the field of Bio-fuels for IC engines and renewable energy. Professor HaengMuk Cho is working in the field of Renewable Energy and Biofuels. E is also a member of many societies, like Korea Society of Automotive Engineers, Korean Society of Energy(Korea), Korea Society of Marine Engineering (Korea) & Korea Society of Environment Engineer (Korea). He has published many national and internal research papers. Most of his papers are indexed in Scopus and SCI.